

1 **METHODS FOR FORMING METAL PARTS HAVING**
2 **SUPERIOR SURFACE CHARACTERISTICS**

3
4 **CROSS-REFERENCE TO RELATED APPLICATIONS**

5 The present application is a Continuation-in-Part of application Serial No. 09/143,643,
6 filed September 3, 1998, which is a Continuation-in-Part of application Serial No.
7 08/993,116 , now U.S. Patent No. 5,956,845, which is the utility patent application of a
8 US provisional application Serial No. 60/033,858, filed December 23, 1996; and relates
9 to an invention disclosed in an Invention Disclosure Document accepted under the
10 Disclosure Document program on or about November 5, 1996 and assigned Disclosure
11 Document No. 407616.

12
13 **BACKGROUND OF THE INVENTION**

14 The present invention pertains to a method for forming metal products. More
15 particularly, the present invention pertains to a method for forming metal products having
16 superior surface characteristics.

17
18 Airfoil parts, such as blades and vanes, are critical components in the gas turbine engines
19 that are used to power jet aircraft or for the generation of electricity. Each airfoil part is
20 an individual unit having a root or attachment section and an airfoil section. The airfoil

1 section has specific chordal and length dimensions that define the airfoil characteristics of
2 the part. The root section is engaged with and held by a housing member. A plurality of
3 the airfoil parts are thus assembled with the housing member to form a disc or ring.
4 Blades, which during operation are rotating part, are assembled into and disc. Vane,
5 which remain stationary, are assembled into a nozzle or vane ring. In the operating gas
6 turbine engine the assembled rings and discs, determine the path of the intake,
7 combustion and exhaust gasses that flow through the engine.

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9 The airfoil part may be either a rotating component or a non-rotating component of the
10 gas turbine engine. If the part is a rotating component, during operation of the turbine
11 engine the part is subjected to centrifugal forces that exert deforming stresses. These
12 deforming stresses cause creep rupture and fatigue problems that can result in the failure
13 of the part. Non-rotating components, such as vanes, are not subjected to centrifugal
14 forces that exert deforming stresses. However, like the rotating parts, these parts are
15 subjected to other deformation such as from hot gas erosion and/or foreign particle
16 strikes. This deformation results in the alteration of the dimensions of the airfoil section.
17 The alteration of the dimensions of the airfoil section can detrimentally modify the
18 airflow through the gas turbine engine which is critical to the engine's performance.

19

1 An example of a non-rotating airfoil part is the 2nd stage vane of the Pratt & Whitney
2 JT8D model 1 through 17R gas turbine engine. This part is manufactured by the “lost
3 wax” or “investment casting” process. The vane is cast from one of several highly
4 alloyed nickel or cobalt-base materials. As a new part in a new gas turbine engine, or as
5 a new spare part in an overhauled engine, it begins its life cycle with a protective
6 diffusion coating on its airfoil surfaces and a wear coating on surfaces known to have
7 excessive wear patterns.

8

9 When the gas turbine engine is operating, the vane will see temperatures of about 1500
10 degree F. Since the vane does not rotate and thus is not subject to creep rupture, its
11 demise is most often influenced by the number of times it is repaired. The reason for this
12 is the repair process itself.

13

14 The repair process consists of the following operations:

15 1). degrease, wash to remove engine carbon, etc.

16 2.) grit blast to remove wear coatings, and any sulfidation which is present

17 3.) chemically remove the diffusion coating

18 4.) blend to remove nicks, dents, etc.

19 5.) weld, grind, polish etc.

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2 The repair operations that remove metal by chemical stripping, grit blasting, blending and
3 polishing shorten the life cycle of the vane. The coating removal is a major contributor
4 because it is diffused into the parent metal. When certain minimum airfoil dimensions
5 cannot be met the part is deemed non-repairable and must be retired from service. Thus,
6 there is a need for a method for repairing gas turbine engine airfoil parts that effectively
7 and efficiently restores the airfoil dimensions of the part.

8

9 On another front, during the manufacture of metal components a coating operation is
10 performed to provide a coating material layer on the surface of a component substrate.
11 The coating material layer is formed to build-up the metal component to desired finished
12 dimensions and to provide the finished product with various surface attributes. For
13 example, an oxide layer may be formed to provide a smooth, corrosion resistant surface.
14 Also, a wear resistant coating, such as Carbide, Cobalt, or TiN is often formed on cutting
15 tools to provide wear resistance.

16

17 Chemical Vapor Deposition is typically used to deposit a thin film wear resistant coating
18 on a cutting tool substrate. For example, to increase the service life of a drill bit,
19 chemical vapor deposition can be used to form a wear resistant coating of Cobalt on a

1 high speed steel (HSS) cutting tool substrate. The bond between the substrate and coating
2 occurs primarily through mechanical adhesion within a narrow bonding interface. During
3 use, the coating at the cutting surface of the cutting tool is subjected to shearing forces
4 resulting in flaking of the coating off the tool substrate. The failure is likely to occur at
5 the narrow bonding interface.

6

7 Figure 12(a) is a side view of a prior art tool bit coated with a wear resistant coating. In
8 this case, the wear resistant coating may be applied by the Chemical Vapor Deposition
9 method so that the entire tool bit substrate receives an even thin film of a relatively hard
10 material, such as Carbide, Cobalt or TiN. Since the coating adheres to the tool bit
11 substrate mostly via a mechanical bond located at a boundary interface, flaking and
12 chipping off the coating off of the substrate is likely to occur during use, limiting the
13 service life of the tool bit. Figure 12(b) is a side view of a prior art tool bit having a fixed
14 wear resistant cutting tip. In this case, a relatively hard metal cutting tip is fixed to the
15 relatively soft tool bit substrate. The metal cutting tip, which is typically comprised of a
16 Carbide or Cobalt alloy, is fixed to the tool bit substrate by brazing. During extended use
17 the tool bit is likely to fail at the relatively brittle brazed interface between the metal
18 cutting tip and the tool substrate, and again, the useful service life of the tool bit is
19 limited.

C O N T E N T S

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Metal alloy components, such as gas turbine parts such as blades and vanes, are often damaged during use. During operation, gas turbine parts are subjected to considerable degradation from high pressure and centrifugal force in a hot corrosive atmosphere. The gas turbine parts also sustain considerable damage due to impacts from foreign particles. This degradation results in a limited service life for these parts. Since they are costly to produce, various repair methods are employed to refurbish damaged gas turbine blades and vanes.

Some examples of methods employed to repair gas turbine blades and vanes include US Patent No. 4,291,448, issued to Cretella et al.; US Patent No. 4,028,787, issued to Cretella et al.; US Patent No. 4,866,828, issued to Fraser; and US Patent No. 4,837,389, issued to Shankar et al.

Cretella '448 discloses a process to restore turbine blade shrouds that have lost their original dimensions due to wear while in service. This reference discloses using the known process of TIG welding worn portions of a part with a weld wire of similar chemistry as the part substrate, followed by finish grinding. The part is then plasma

1 sprayed with a material of similar chemistry to a net shape requiring little or no finishing.
2 The part is then sintered in an argon atmosphere. The plasma spray process used in
3 accordance with Cretella '448 results in a coating porosity of about 5.0%. Even after
4 sintering the coating remains attached to the substrate and weld material only be a
5 mechanical bond at an interface bonding layer making the finished piece prone to
6 chipping and flaking.

7

8 Cretella '787 discloses a process for restoring turbine vanes that have lost their original
9 dimensions due to wear while in service. Again, a conventional plasma spray process is
10 used to build up worn areas of the vane before performing a sintering operation in a
11 vacuum or hydrogen furnace. The porosity of the coating, and the interface bonding
12 layer, results in a structure that is prone to chipping and flaking.

13

14 Fraser discloses a process to repair steam turbine blades or vanes that utilize some
15 method of connecting them together (i.e. lacing wire). In accordance with the method
16 disclosed by Fraser, the area of a part that has been distressed is removed and a new piece
17 of like metal is welded to the part. The lacing holes of the part are plug welded. The part
18 is then subjected to hot striking to return it to its original contour, and the lacing holes are
19 re-drilled.

1 Wilson discloses a turbine engine blade having a single crystal body having an airfoil
 2 section and an attachment or root section. A layer of polycrystalline superalloy is applied
 3 to the attachment section, preferably by plasma spraying. The coated blade is HIPed and
 4 then solution heat-treated to optimize the polycrystalline microstructure.

5

6 Gupta discloses a process for producing high temperature corrosion resistant metal
 7 articles. A ductile metallic overlay is formed on the surface of an article substrate, and an
 8 outer layer is applied over the overlay. The article is then subjected to a HIP treatment to
 9 eliminate porosity and create an inter-diffusion between the outer layer the overlay and
 10 the substrate.

11

12 None of these prior attempts provide for the effective and efficient restoration of the
 13 critical airfoil dimensions of a gas turbine engine airfoil part. Typically, an airfoil part
 14 will have to be discarded after it has gone through a certain number of repair cycles. The
 15 stripping of the protective coating on the part during the repair process is a major
 16 contributing factor resulting in the discarding of the part. After a number of repair cycles
 17 the part simply does not have the minimum dimensional characteristics necessary for it to
 18 perform its intended function. Therefore, there is a need for a method for repairing gas

1 turbine engine airfoil parts that effectively and efficiently restores the critical airfoil
2 dimensions of the part.
3
4 Turbine engine airfoil parts, such as vanes, are manufactured to precise tolerances that
5 determine the airflow characteristics for the part. The class of a turbine vane is the
6 angular relationship between the airfoil section and the inner and outer buttresses of the
7 vane. This angular relationship has a direct bearing on the angle of attack of the airfoil
8 section during the operation of the gas turbine engine. Over time, the angular
9 relationship between the airfoil section and the inner and outer buttresses of the vane may
10 become altered due to, for example, deformation of the airfoil section from engine
11 operation and repair processes and the like. Or, the particular angular relationship of the
12 airfoil section and the inner and outer buttresses as originally manufactured may need to
13 be changed to improve engine performance. In any event, there is a need for a method of
14 restoring or reclassifying a gas turbine engine airfoil part.

16 SUMMARY OF THE INVENTION

17 The present invention overcome the drawbacks of the conventional art for repairing gas
18 turbine engine airfoil parts. It is an object of the present invention to provide a method
19 forming a metal part having superior surface characteristics. It is another object of the

1 In accordance with the present invention, a metal alloy workpiece substrate is provided
 2 have pre-process dimensions. The dimensional differences are determined between the
 3 pre-process dimensions of the workpiece substrate and desired post-process dimensions
 4 of a post-process metal product formed from the workpiece substrate. A build-up
 5 thickness is determined of coating material required to obtain the desired post-process
 6 dimensions of the post-process metal product. A high-density coating process is
 7 performed to coat the workpiece substrate with a coating material to build-up a thickness
 8 of coating material effective to obtain desired finished dimensions after performing a
 9 sintering heat treatment process and/or a hot isostatic pressing treatment. The sintering
 10 heat treatment is performed on the coated workpiece substrate to densify the coating
 11 material. Then, the hot isostatic pressing treatment is performed to obtain the post-
 12 process metal product having the desired post-process dimensions and having diffusion
 13 bonding between the coating material and the workpiece substrate.

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15 Also accordance with another aspect of the present invention, the dimensional differences
 16 between pre-repaired dimensions of a turbine engine airfoil part and desired post-repair
 17 dimensions of the turbine engine airfoil part are determined. A build-up thickness of
 18 coating material required to obtain the desired post-repair dimensions of the turbine
 19 engine airfoil part is determined. A high-density coating process, such as HVOF, is used

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In the typical application of the inventive method, the metal alloy substrate of the turbine engine airfoil part will comprise a nickel or cobalt-base superalloy. The step of performing the high-density coating process may thus include performing a high-density coating process such as a hyper velocity oxy-fuel thermal spray process or a detonation gun process to apply a high-density coating having the same nickel or cobalt-base superalloy composition as the metal alloy substrate.

The sintering heat treatment comprises sintering at a temperature at or about 2150 degrees F for about 2 hours, which has been found to effectively prevent gas entrapment of the applied high-density coating during the hot isostatic pressing process. In the case of a nickel or cobalt-base superalloy substrate, the hot isostatic pressing treatment can be performed at a temperature of about 2200F in about 15 KSI argon for about 4 hours. The parameters of the hot isostatic pressing treatment typically call for heating the engine part to a temperature that is substantially 80% of the melting point of the metal alloy; and pressurizing the engine part to a pressure substantially between 20 and 50 percent of the yield strength of the metal alloy in an inert gas atmosphere.

1 The dimensional differences between the pre-repaired dimensions of the turbine engine
2 airfoil part and the desired post-repair dimensions of the turbine engine airfoil part are
3 measured from at least one of the chordal and length dimensions of the airfoil part. By
4 performing the inventive method for repairing a gas turbine engine airfoil part, the post-
5 repair dimensions are equal to the dimensions necessary for effectively returning the part
6 to active service. The diffusion bonding between the coating material and the substrate
7 ensures that the repaired airfoil part is robust enough to withstand the highly demanding
8 environmental conditions present in an operating gas turbine engine.

9

10 In accordance with another embodiment of the inventive method, a turbine engine part,
11 which is comprised of a metal or metal alloy, is first cleaned. If necessary, eroded
12 portions of the turbine engine part are welded using a weld material comprised of the
13 same metal or metal alloy as the parent or original metal engine part. The welding
14 operation is performed to build up heavily damaged or eroded portions of the turbine
15 engine part. If the part is not heavily damaged, the welding operation may be obviated.
16 The welding operation will typically produce weld witness lines. The weld witness lines
17 are ground flush to prevent blast material from becoming entrapped in the weld witness
18 lines. Portions of the engine part that are not to be HVOF sprayed are masked, and the
19 engine part is again cleaned in preparation for HVOF spraying. HVOF plasma spraying

1 mechanical properties that allow the part to be safely returned to service. Thus, the
2 inventive method of repairing a turbine engine airfoil part offers substantial savings
3 because it provides for the efficient and effective repairing of expensive engine parts
4 which otherwise might have been discarded.

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6 In accordance with another aspect of the present invention, a method of forming a metal
7 product having diffusion bonding occurring between a metal substrate and an applied
8 coating is provided. The first step of the inventive method is to determine the attributes
9 of a final workpiece product. For example, if the final workpiece product is a cutting tool
10 the attributes include a wear resistant surface formed on a relatively inexpensive tool
11 substrate. An appropriate substrate composition is then determined depending on the
12 selected attributes. In the example of a cutting tool, the substrate composition may be
13 high speed steel, which is relatively inexpensive to form but durable enough for its
14 intended purpose. A workpiece substrate is formed to near-finished dimensions, using
15 known processes such as casting, extruding, molding, machining, etc. An appropriate
16 coating material composition is determined depending on the selected attributes. Again,
17 in the example of a cutting tool, the coating material could be selected from a number of
18 relatively hard and durable metals and alloys such as Cobalt, Carbide, TiN, etc. The

1 selection of both the substrate and coating composition also depends on their
 2 metallurgical compatibility with each other.
 3
 4 The workpiece substrate is prepared for a high-density coating process. The preparation
 5 may include cleaning, blasting, machining, masking or other like operations. Once the
 6 workpiece substrate has been prepared, a high-density coating process is performed to
 7 coat the workpiece substrate. The coating material is built-up to a thickness that is
 8 effective to obtain desired finished dimensions after performing a hot isostatic pressing
 9 treatment (described below). The high-density coating process may comprise performing
 10 a hyper velocity oxy-fuel thermal spray process. In the case of HVOF, a fuel gas and
 11 oxygen are used to create a combustion flame at 2500 to 3100°C. The combustion takes
 12 place at a very high chamber pressure and a supersonic gas stream forces the coating
 13 material through a small-diameter barrel at very high particle velocities. The HVOF
 14 process results in extremely dense, well-bonded coatings. Typically, HVOF coatings can
 15 be formed nearly 100% dense, with at a porosity of about 0.5%. The high particle
 16 velocities obtained using the HVOF process results in relatively better bonding between
 17 the coating material and the substrate, as compared with other coating methods such as
 18 the conventional plasma spray method or the chemical vapor deposition method.
 19 However, the HVOF process forms a bond between the coating material and the substrate

1 strength of the material. Pressurization is achieved by pumping an inert gas, such as
2 Argon, into a pressure vessel. Within the pressure vessel is a high temperature furnace,
3 which heats the gas to the desired temperature. The temperature and pressure is held for
4 a set length of time, and then the gas is cooled and vented.

5

6 In accordance with the present invention, the HIP treatment process is performed on a
7 HVOF coated substrate to convert the adhesion bond, which is merely a mechanical
8 bond, to a diffusion bond, which is a metallurgical bond. In accordance with the present
9 invention, an HVOF coating process is used to apply the coating material having
10 sufficient density to effectively undergo the densification changes that occur during the
11 HIP process. After the HVOF spray material is applied, a sintering heat treatment process
12 can be performed to further densify the coating to prevent gas entrapment of the coating
13 material and/or the diffusion bonding area during the hot isostatic pressing process. If the
14 coating material and the workpiece substrate are comprised of the same metal
15 composition, then the diffusion bonding results in a particularly seamless transition
16 between the substrate and the coating.

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18 The inventive method can be used for forming a metal product having a wear resistant
19 surface. This method can be employed to produce, for example, a long lasting cutting

1 dimensions. The HVOF coated, cast part is then HIP treated as described herein to obtain
2 a finished part having desired dimensions and surface characteristics.

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4 In accordance with this aspect of the invention, a cast metal workpiece is provided. The
5 cast metal workpiece may be formed from any conventional casting method such as:
6 investment, sand and resin shell casting.

7

8 The cast metal workpiece is machined, if necessary, to near-finished dimensions. A high-
9 density coating process, such as a hyper velocity oxy-fuel thermal spray process (HVOF),
10 is performed to coat the workpiece substrate with a coating material. The coating
11 material is built-up to a thickness effective to obtain desired finished dimensions after
12 performing a hot isostatic pressing treatment. A sintering heat treatment step may be
13 performed improve the density of the coating material and prevent gas entrapment during
14 the hot isostatic pressing treatment. The hot isostatic pressing treatment is performed on
15 the coated workpiece substrate to obtain a metal product having the desired finished
16 dimensions and diffusion bonding between the coating material and the workpiece
17 substrate.

18

1 In accordance with another aspect of the present invention, the reclassification of a gas
2 turbine engine airfoil part is obtained. The dimensional differences between pre-
3 reclassified dimensions of the buttresses of a turbine engine airfoil part and desired post-
4 reclassified dimensions of the buttresses are determined. That is, the change in shape of
5 the inner buttress and outer buttress necessary to obtained a desired angular relationship
6 between the airfoil section and the buttresses is determined. Build-up thickness of
7 coating material required to obtain the desired post-reclassified dimensions of the
8 buttresses is determined. A high-density coating process, such as HVOF, is used to coat
9 the buttresses of the turbine engine airfoil part with a coating material. The portions of
10 the part that are not to be built up, such as the airfoil section and parts of the buttresses,
11 may be masked before applying the high-density coating. Also, some of the coated
12 surfaces of the part may need to be built up more than others. The coating material is
13 applied to the determined build-up thickness of coating material effective to obtain the
14 desired post-reclassification dimensions after performing a hot isostatic pressing
15 treatment, and after the selective removal of some of the original buttress material and
16 some of the built up coating material. A sintering heat treatment may be performed
17 before the hot isostatic pressing treatment.

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1 As discussed herein, the coating material comprises a metal alloy capable of forming a
2 diffusion bond with the substrate of the turbine engine airfoil part. After the coating
3 material is applied, the sintering heat treatment process may be performed to prevent gas
4 entrapment of the coating material and/or the diffusion bonding area during the hot
5 isostatic pressing process. Then, the hot isostatic pressing (HIP) process is performed so
6 that the buttresses of the turbine engine airfoil part have a robust diffusion bonding
7 between the coating material and the original material of the buttresses. Having built up
8 the appropriate dimensions of the inner buttress and outer buttress, the reclassification of
9 the part is obtained by selectively removing the original buttress material and, if
10 necessary, some of the built up material until the angular relationship between the airfoil
11 section and the inner and outer buttresses is obtained. The material can be removed
12 through milling, grinding, or other suitable and well known machining operations.
13 Further, to facilitate obtaining the correct dimensions the centerline position of the airfoil
14 part can be located and held by mounting the part in a suitable holding fixture when
15 machining the buttresses.

16

17 The fixture may be so constructed so that a vane that has at least a minimum amount of
18 material built up on its buttresses can be machined and reclassified. In this case, it may
19 not be necessary to determine the dimensional differences or the required build-up

1 thickness. Rather, the inventive high density coating and HIPing process (and, if needed
2 sintering) can be performed to build up at least the minimum amount of material
3 diffusion bonded to the buttresses. Then, the vane is placed in the fixture and the excess
4 material (both original buttress material and the built-up material) is machined until the
5 buttresses have been reshaped and the vane reclassified as intended.

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7 **BRIEF DESCRIPTION OF THE DRAWINGS**

8 Figure 1(a) is a flow chart showing the steps of the inventive method for repairing a gas
9 turbine engine airfoil part;

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11 Figure 1(b) is a flow chart showing the steps of the inventive method of forming metal
12 products and metal components having a wear resistant coating;

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14 Figure 2(a) is a schematic view of a tool substrate provided in accordance with the
15 inventive method of forming metal components having a wear resistant coating;

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17 Figure 2(b) is a schematic view of the tool substrate having a wear resistant coating
18 applied using an HVOF thermal spray process in accordance with the inventive method
19 of treating metal components having a wear resistant coating;

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2 Figure 2(c) is a schematic view of the HVOF spray coated tool substrate undergoing a

3 HIP treatment process in a HIP vessel in accordance with the inventive method of

4 forming metal components having a wear resistant coating;

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6 Figure 2(d) is a schematic view of the final HVOF spray coated and HIP treated tool

7 having a wear resistant coating layer diffusion bonded to the tool substrate in accordance

8 with the inventive method of forming metal components having a wear resistant coating;

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10 Figure 3(a) is a schematic perspective view of a cast metal component undergoing a

11 machining operation in accordance with the inventive method of forming a metal

12 product;

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14 Figure 3(b) is a schematic perspective view of the machined cast metal component in

15 accordance with the inventive method of forming a metal product;

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17 Figure 3(c) is a schematic perspective view of the machined cast metal component having

18 a coating applied using an HVOF thermal spray process in accordance with the inventive

19 method of forming a metal product;

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Figure 3(d) is a schematic perspective view of the HVOF spray coated machined cast metal component undergoing a HIP treatment process in a HIP vessel in accordance with the inventive method of forming a metal product;

Figure 3(e) is a schematic perspective view of the final HVOF spray coated and HIP treated machined cast metal product having a coating layer diffusion bonded to the machined cast metal component in accordance with the inventive method of forming a metal product;

Figure 4 is a flow chart showing the steps of the inventive method of repairing a turbine engine part;

Figure 5(a) is a schematic side view of a worn turbine engine part before undergoing the inventive method of repairing a turbine engine part;

Figure 5(b) is a schematic cross-sectional view of the worn turbine engine part before undergoing the inventive method of repairing a turbine engine part;

1 Figure 6(a) is a schematic side view of the worn turbine engine part showing the worn
2 areas to be repaired using the inventive method of repairing a turbine engine part;

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4 Figure 6(b) is a schematic cross-sectional view of the worn turbine engine part showing
5 the worn areas to be repaired using the inventive method of repairing a turbine engine
6 part;

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8 Figure 7(a) is a schematic side view of the worn turbine engine part showing the worn
9 areas filled in with similar weld material in accordance with the inventive method of
10 repairing a turbine engine part;

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12 Figure 7(b) is a schematic cross-sectional view of the worn turbine engine part showing
13 the worn areas filled in with similar weld material in accordance with the inventive
14 method of repairing a turbine engine part;

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16 Figure 8(a) is a schematic side view of the welded turbine engine part showing areas to
17 be built up with similar coating material using an HVOF spray coating process in
18 accordance with the inventive method of repairing a turbine engine part;

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1 Figure 8(b) is a schematic cross-sectional view of the welded turbine engine part showing
2 areas to be built up with similar coating material using an HVOF spray coating process in
3 accordance with the inventive method of repairing a turbine engine part;

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5 Figure 9(a) is a schematic side view of the HVOF built up, welded turbine engine part
6 showing an area masked before performing the HVOF spray coating process in
7 accordance with the inventive method of repairing a turbine engine part;

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9 Figure 9(b) is a schematic cross-sectional view of the HVOF built up, welded turbine
10 engine part in accordance with the inventive method of repairing a turbine engine part;

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12 Figure 10 is a schematic view of the HVOF built up, welded turbine engine part
13 undergoing a HIP treatment process in a HIP vessel in accordance with the inventive
14 method of repairing a turbine engine part;

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16 Figure 11(a) is a schematic side view of the final HVOF spray coated and HIP repaired
17 turbine engine part having a similar metal coating layer diffusion bonded to the original
18 parent substrate and welded portions in accordance with the inventive method of
19 repairing a turbine engine part;

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2 Figure 11(b) is a schematic cross-sectional view of the final HVOF spray coated and HIP
3 repaired turbine engine part having a similar metal coating layer diffusion bonded to the
4 original parent substrate and welded portions in accordance with the inventive method of
5 repairing a turbine engine part;

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7 Figure 12(a) is a side view of a prior art tool bit coated with a wear resistant coating;

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9 Figure 12(b) is a side view of a prior art tool bit having a fixed wear resistant cutting tip;

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11 Figure 13 is a flow chart showing the steps of the inventive method for reclassifying a gas
12 turbine engine airfoil part;

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14 Figure 14(a) is a front view of a vane from a gas turbine engine showing the airfoil
15 section, the outer buttress and the inner buttress;

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17 Figure 14(b) is a partial top view of the vane shown in Figure 14(a) showing the outer
18 buttress and angle α indicating the angular relationship between the airfoil and the outer
19 buttress;

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2 Figure 14(c) is a partial bottom view of the vane shown in Figure 14(a) showing the inner
3 buttress and angle α' indicating the angular relationship between the airfoil and the inner
4 buttress;

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6 Figure 14(d) is a partial left-side view of the vane shown in Figure 14(a) showing the
7 leading edge foot of the inner buttress and the outer foot front face of a buttress rail of the
8 outer buttress; and

9

10 Figure 14(e) is a partial right-side view of the vane shown in Figure 14(a) showing the
11 trailing edge foot of the inner diameter buttress and the other buttress rail of the outer
12 diameter buttress.

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14 **DETAILED DESCRIPTION OF THE INVENTION**

15 For purposes of promoting an understanding of the principles of the invention, reference
16 will now be made to the embodiments illustrated in the drawings and specific language
17 will be used to describe the same. It will nevertheless be understood that no limitation of
18 the scope of the invention is thereby intended, there being contemplated such alterations
19 and modifications of the illustrated device, and such further applications of the principles

1 of the invention as disclosed herein, as would normally occur to one skilled in the art to
2 which the invention pertains.

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4 Referring to Figure 1(a), in accordance with the present invention, the dimensional
5 differences between pre-repaired dimensions of a turbine engine airfoil part and desired
6 post-repair dimensions of the turbine engine airfoil part are determined (Step One-B).

7 The turbine engine airfoil part has a substrate comprised of a superalloy. A build-up
8 thickness of coating material required to obtain the desired post-repair dimensions of the
9 turbine engine airfoil part is determined (Step Two). A high-density coating process,

10 such as HVOF, is used to coat the turbine engine airfoil part with a coating material to the
11 determined build-up thickness of coating material effective to obtain the desired post-

12 repair dimensions after performing a sintering heat treatment and a hot isostatic pressing
13 treatment (Step Three). The coating material comprises a metal alloy capable of forming

14 a diffusion bond with the substrate of the turbine engine airfoil part. After the coating

15 material is applied, a sintering heat treatment process is performed to prevent gas

16 entrapment of the coating material and/or the diffusion bonding area during the hot

17 isostatic pressing process (Step Four). Then, the hot isostatic pressing process is

18 performed to obtain a post-repair turbine engine airfoil part having the desired post-repair

1 dimensions and having diffusion bonding between the coating material and the turbine
2 engine airfoil substrate (Step Five).

3

4 In accordance with the present invention, a protective coating must be first removed from
5 the turbine engine airfoil part prior to performing the high-density coating process (Step
6 One-A). After performing the hot isostatic pressing process, a protective coating may be
7 re-applied (Step Six). In this case, the build-up thickness may determined in Step Two to
8 take into consideration the additional thickness of the post-repaired part due to the
9 addition of the protective coating.

10

11 Typically, this protective coating is present on an airfoil part to protect it from the hot
12 corrosive environment it experiences during service. This protective coating must be
13 removed during the inspection and/or repair process. After undergoing a number of
14 inspection and/or repair cycles, the airfoil part was conventionally discarded simply
15 because the airfoil dimensions of the part were too deformed for the part to be usable.
16 However, in accordance with the present inventive repair method, the airfoil dimensions
17 are restored and a robust repaired airfoil part is obtained

18

1 In the typical application of the inventive method, the metal alloy substrate of the turbine
2 engine airfoil part will comprise a nickel or cobalt-base superalloy. The step of
3 performing the high-density coating process (Step Three) may thus include performing a
4 high-density coating process such as a hyper velocity oxy-fuel thermal spray process or a
5 detonation gun process to apply a high-density coating having the same nickel or cobalt-
6 base superalloy composition as the metal alloy substrate.

7

8 In an embodiment of the invention in which the coating material and the substrate alloy
9 comprise INCO713C nickel or cobalt-base superalloy, the sintering heat treatment (Step
10 Four) comprises sintering at a temperature at or about 2150 degrees F for about 2 hours,
11 which has been found to effectively prevent gas entrapment of the applied high-density
12 coating during the hot isostatic pressing process. In the case of the nickel or cobalt-base
13 superalloy substrate, an effective hot isostatic pressing treatment (Step Five) can be
14 performed at a temperature of about 2200F in about 15 KSI argon for about 4 hours. The
15 parameters of the hot isostatic pressing treatment typically call for heating the engine part
16 to a temperature that is substantially 80% of the melting point of the metal alloy; and
17 pressurizing the engine part to a pressure substantially between 20 and 50 percent of the
18 yield strength of the metal alloy in an inert gas atmosphere.

19

1 The dimensional differences between the pre-repaired dimensions of the turbine engine
2 airfoil part and the desired post-repair dimensions of the turbine engine airfoil part are
3 measured from at least one of the chordal and length dimensions of the airfoil part (Step
4 One-B). By performing the inventive method for repairing a gas turbine engine airfoil
5 part, the post-repair dimensions are equal to the dimensions necessary for effectively
6 returning the part to active service. The obtained diffusion bonding between the coating
7 material and the substrate ensures that the repaired airfoil part is robust enough to
8 withstand the highly demanding environmental conditions present in an operating gas
9 turbine engine. Thus, the present invention offers substantial cost savings over having to
10 replace a turbine gas engine airfoil part which otherwise might have been discarded.

12 The present invention can be used as a process for restoring critical gas path area
13 dimensions in cast nickel or cobalt-base superalloy vane components. These dimensions
14 may become altered due to erosion or particle strikes during the service life of the part,
15 and/or may become altered during an inspection or repair process wherein a protective
16 coating is stripped from the part.

18 The inventive process, referred to herein as "recast", briefly consists of applying a pre-
19 alloyed metal powder, compositionally identical to the superalloy used in the original

1 manufacture of the vane being repaired, directly on dimensionally discrepant surfaces,
2 densifying the metal powder coating, and causing it to bond to the affected surface.

3

4 More specifically, in the preferred embodiment of the invention candidate recast surfaces
5 are abrasively clean, thermal sprayed using high velocity oxy fuel processes (HVOF),
6 sintered, and hot isostatically pressed (HIPed).

7

8 Thermal spray metal powders, produced by a vacuum/inert gas atomization processes, are
9 applied directly to the dimensionally discrepant surfaces of a turbine engine airfoil part
10 using robotic HVOF processes carefully controlled to produce dense coatings while
11 minimizing thermal gradients and oxidative solute losses.

12

13 Properly applied HVOF coatings are dense but sometimes contain interconnected
14 micropores. In accordance with the present invention, such "porous" HVOF coatings are
15 more fully densified by sintering and subsequently diffusion-bonded to substrate surfaces
16 by HIPing at temperatures and pressures commensurate with the nickel or cobalt-base
17 alloy under consideration.

18

1 articles vary depending on the relative volume fraction of the recast coating, the specific
2 alloy(s) under consideration, and processing history.

3

4 **Example of Recast INCO713C/cast INCO713C Composite Mechanical Properties**

5 **Obtained in Accordance with the Present Invention:**

6 Representative tensile and stress-rupture properties of recast INCO713C/cast INCO713C
7 composite test specimens were measured to more fully elucidate the recast process.

8

9 INCO713C was selected as the base nickel or cobalt-base superalloy for measurement
10 because it is specified by a large number of engine manufactures for gas turbine
11 component applications, and is bill-of-material for JT8D second-stage vanes, a candidate
12 component for the inventive recast repair method.

13

14 Near cast-to-size INCO713C test bars were machined into ASTM proportioned
15 mechanical test specimens with tapered (approximately three percent) gauge lengths.
16 The average minimum gauge length diameter was 0.2137 inches.

17

18 The machined test specimens were grit-blasted with silicon carbide, ultrasonically
19 cleaned, and robotically sprayed with INCO713C powder using Diamond Jet HVOF

processes. The composition of the INCO713C powder used in these evaluations is shown in Table I.

Table I: Certified Compositions of INCO713C Atomized Powder and Cast-To-Size Test Bars

<u>Element</u>	<u>EMS 55079</u>	<u>Atomized Powder</u>	<u>Cast-To-Size Test Bars (Heat # 8616)</u>
Nickel	Balance	Balance	Balance
Chromium	11.0 to 13.0	13.6	13.67
Aluminum	5.5 to 6.5	5.86	5.61
Molybdenum	3.8 to 5.2	4.39	4.06
Columbium	1.5 to 2.5	2.1	2.08
Titanium	0.4 to 1.0	0.9	0.84
Zirconium	0.05 to 0.15	0.07	0.05
Carbon	0.05 to 0.07	0.1	0.13
Boron	0.005 to 0.015	0.01	0.008
Cobalt	1.00 max.	<0.01	<0.05
Silicon	0.50 max.	0.09	<0.05
Copper	0.05 max.	0.04	<0.05
Iron	0.25 max.	0.18	<0.05
Manganese	0.25 max.	0.01	<0.05
Sulfur	0.015 max.	0.002	<0.05
Phosphorus	0.015 max.		

Sufficient HVOF coating was applied to increase the composite specimen gauge length diameter to approximately 0.250 inches. The sprayed test bars were then sintered at 2150F for 2 hours in vacuum, HIPed at 2200F in 15 KSI argon for 4 hours in a standard

1 commercial HIP toll cycle, and tested for room temperature tensile and elevated-
2 temperature stress-rupture.
3

4 The composite test specimens used for these measurements were nominally comprised of
5 28 percent recast INCO713C and 72 percent as-cast INCO713C. The recast INCO713C
6 percentage varied, however, from 25.5 to 30.9 percent depending on precise machined
7 and sprayed specimen dimensions.
8

9 **Mechanical Properties:**

10 The room temperature tensile and 1800F stress-rupture properties of the as-cast
11 INCO713C core material used in these measurements are summarized in Table II.
12

13 Table II: INCO713C Heat # 8616 Qualification Tests
14

15 1. Room Temperature Tensile
16

17 a. 0.2% Y.S. 108 KSI
18 UTS 126 KSI
19 Elongation 6.0%
20

21 b. 0.2% Y.S. 112.2 KSI 111.0 KSI
22 UTS 126 KSI 135.7 KSI
23 Elongation 6.3% 6.7%
24

25 2. Stress-Rupture
26

1	a.	Temperature	Stress	Rupture Life	Elongation
2					
3		1800F	22 KSI	30.0 hours	
4		1800F	24 KSI	14.8 hours	14.0%
5					
6	b.	1800F	22 KSI	55.3 hours	9.1%
7		1800F	22 KSI	58.2 hours	10.3%
8					

9 The room-temperature tensile and 1800F stress-rupture properties of the 28 percent recast

10 INCO713C composite test specimens are summarized in Table III.

11

12 Table III: Measured Tensile and Stress-Rupture Properties of Composite Cast/Recast
13 INCO713C Test Specimens

14

15 1. Room Temperature Tensile Properties

16

17	<u>Specimen</u>	<u>0.2 YS</u>	<u>UTS</u>	<u>Elongation</u>
18	#1	123.3 KSI	150.3 KSI	5.6%
19	#2	122.0 KSI	151.5 KSI	6.6%
20	#3	122.4 KSI	148.1 KSI	6.7%
21				
22	Average	122.4 KSI	150.0 KSI	6.3%

23

24

25 2. Stress-Rupture Properties

26

27	<u>Specimen</u>	<u>Rupture Life</u>	<u>Elongation</u>	<u>Reduction in</u>
28				<u>Area</u>
29	@ 1800F/22 KSI			
30	(stress calculated on cast INCO713C cross-section only)			
31				
32	#4	60.9 hrs.	10.7%	21.1%
33	#5	55.9 hrs.	6.3%	17.8%
34	#6	60.9 hrs.	7.1%	16.8%

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@ 1600F/42 KSI
(stress calculated on cast INCO713C cross-section only)

#5	202.5 hrs.	6.9%	12.2%
#6	>212.5 hrs.	4.9%	8.6%

The room temperature yield and ultimate tensile strengths of the 28 percent recast INCO713C composite test specimens were approximately 11 percent higher than those of as-cast INCO713C core material. The room temperature ductility of the 28 percent recast INCO713C composite test specimens was virtually identical to that of the as-cast INCO713C core material.

The as-cast INCO713C core material and the 28 percent recast INCO713C composite test specimens were tested for stress-rupture at 1800F under “constant load” conditions to experimentally assess the effect of the recast process on the sustained, high-temperature, load-bearing capacity of as-cast INCO713C.

The approximate time to rupture as-cast INCO713C at 1800F/22 KSI, as estimated from available “Larsen-Miller” correlations, is 48 hours. The time to rupture the as-cast INCO713C core material test bars at 1800F/22 KSI was 30.0 hours. The average time to rupture machined as-cast INCO713C test specimens at 1800F/22 KSI was 56.5 hours.

1 The average as-cast INCO713C 1800F/22 KSI stress-rupture life was 45 hours, plus or
2 minus 15 hours.

3

4 The 28 percent recast INCO713C composite test specimens were tested at 1800F under
5 loads sufficient to produce 22 KSI stress based on as-cast INCO713C substrate
6 dimensions rather than composite test specimen dimensions. Test loads ranged from 795
7 to 799 pounds (797 pounds average) depending on precise as-cast INCO713C machined
8 diameters. Corresponding composite specimen stresses ranged from 15 to 16 KSI.

9

10 The average time to rupture the 28 percent INCO713C composite test specimens under
11 such "constant load" test conditions was 60.9 hours at 1800F.

12

13 **Data Analyses:**

14 The data summarized in Table III show that the recast process augments the room
15 temperature tensile properties of as-cast INCO713C.

16

17 Assuming the room temperature tensile properties of the as-cast INCO713C substrate
18 remain unchanged by the thermal treatments associated with the recast process, "rule of
19 mixture" analyses of the room temperature 28 percent recast INCO713C composite

1 tensile data summarized in Table III indicate that the recast INCO713C portion of the
2 composite has the following room temperature tensile properties:

3

4	150 KSI	0.2% yield strength
5	190 KSI	ultimate tensile strength
6	5.8%	elongation

7

8 The data summarized in Table III similarly show that the recast process augments the
9 sustained high-temperature, load-bearing capacity of as-cast INCO713C.

10

11 "Load partitioning analysis", for lack of a better description, were used to distinguish the
12 stress-rupture strength properties of the recast INCO713C coating from those of the as-
13 cast INCO713C substrate.

14

15 "Larsen-Miller" stress-rupture data correlation's suggest that the stress required to
16 increase the 1800F rupture life of an as-cast INCO713C substrate specimen to 60.9 hours
17 is only 21 KSI. The load required to develop a stress of 21 KSI, based on an average
18 0.2145 inch as-cast INCO713C substrate diameter, is 759 pounds. Since 797 pounds
19 were applied to the 28 percent recast INCO713C composite specimens tested at 1800F/16
20 KSI, it follows that the balance of the load (39 pounds) was accommodated by the recast
21 INCO713C coating.

1

2 Since the cross-sectional area of the recast INCO713C coating in the 28 percent recast
3 INCO713C composite specimens was 0.0161 square inches, the recast INCO713C
4 coating stress was 2.4 KSI. The 1800F/60.9 hour stress-rupture strength of recast
5 INCO713C is, therefore, approximately 2.4 KSI.

6

7 Two 28 percent recast INCO713C composite test specimens were similarly tested in
8 stress-rupture at 1600F under loads calculated to develop a stress of 42 KSI based on as-
9 cast INCO713C substrate dimensions.

10

11 One of the 28 percent recast INCO713C composite test specimens ruptured in 202.5
12 hours at 1600F/42 KSI (based on as-cast substrate dimensions) while the other was
13 arbitrarily terminated without rupture after 212.5 hours. An as-cast INCO713C test
14 specimen might be expected to rupture in approximately 100 hours at 1600F/42 KSI.

15

16 "Load-partitioning analyses" of these 1600F stress-rupture test results suggest that the
17 1600F/200 hour stress-rupture strength of the recast INCO713C coating is greater than 8
18 KSI.

19

1 The stress-rupture properties of the recast INCO713C coating, as inferred from “load
2 partitioning analyses”, generally correspond to those of wrought nickel or cobalt-base
3 levels through post HIP heat treatments.

4
5 The experimental data discussed above indicate that recast INCO713C coating:

- 6
7 1. have intrinsically higher room temperature tensile strength than as-cast INCO713C;
8 and,
9 2. have intrinsic stress-rupture strengths approximately equivalent to wrought nickel or
10 cobalt-base alloys.

11
12 More importantly, the experimental data presented and discussed in this study
13 convincingly demonstrate that the recast process augments the room-temperature tensile
14 and sustained high-temperature, load-bearing capacities of as-cast INCO713C.

15
16 In accordance with another aspect of the present invention, a method of forming metal
17 products and components having a durable wear resistant coating is provided. Figure
18 1(b) is a flow chart showing the steps of the inventive method of forming metal products
19 and metal components having a wear resistant coating. This method obtains a metal

1 product having robust diffusion bonding occurring between a metal substrate and an
 2 applied coating. The first step of the inventive method is to determine the attributes of a
 3 final workpiece product (Step One). For example, if the final workpiece product is a
 4 cutting tool the attributes include a wear resistant surface formed on a relatively
 5 inexpensive tool substrate 10. If the final workpiece is a cast metal component, a
 6 decorative, smooth final surface may be desired on a cast substrate 16.

7
 8 An appropriate substrate composition is then determined (Step Two) depending on the
 9 selected attributes. In the example of a cutting tool, the substrate composition may be
 10 high speed steel, which is relatively inexpensive to form but durable enough for its
 11 intended purpose. In the case of a cast metal component, the cast workpiece substrate
 12 can be formed from cast iron or aluminum (or other cast metal or metal alloy). A
 13 workpiece substrate is formed to near-finished dimensions (Step Three), using known
 14 processes such as casting, extruding, molding, machining, etc. An appropriate coating
 15 material 12 composition is determined depending on the selected attributes (Step Four).
 16 Again, in the example of a cutting tool the coating material 12 could be selected from a
 17 number of relatively hard and durable metals and alloys such as Cobalt, Carbide, TiN,
 18 etc. In the example of the cast metal component, aluminum oxide may be chosen to
 19 provide both a decorative and corrosion resistant surface. The selection of both the

1 substrate and coating composition also depends on their metallurgical compatibility with
2 each other.

3

4 The workpiece substrate is prepared for a high-density coating process (Step Five). The
5 preparation may include cleaning, blasting, machining, masking or other like operations.

6 Once the workpiece substrate has been prepared, a high-density coating process is
7 performed to coat the workpiece substrate (Step Six). The coating material 12 is built-up

8 to a thickness that is effective to obtain desired finished dimensions after performing a
9 hot isostatic pressing treatment (described below). The high-density coating process may

10 comprise performing a hyper velocity oxy-fuel thermal spray process. In the case of

11 HVOF, a fuel gas and oxygen are used to create a combustion flame at 2500 to 3100°C.

12 The combustion takes place at a very high chamber pressure and a supersonic gas stream
13 forces the coating material 12 through a small-diameter barrel at very high particle

14 velocities. The HVOF process results in extremely dense, well-bonded coatings.

15 Typically, HVOF coatings can be formed nearly 100% dense, with at a porosity of about
16 0.5%.

17

18 The high particle velocities obtained using the HVOF process results in relatively better
19 bonding between the coating material 12 and the substrate, as compared with other

1 coating methods such as the Conventional Plasma spray method or the Chemical Vapor
2 Deposition method. However, the HVOF process also forms a bond between the coating
3 material 12 and the substrate that occurs primarily through mechanical adhesion at a
4 bonding interface. As will be described below, in accordance with the present invention
5 this mechanical bond is converted to a metallurgical bond by creating a diffusion bond
6 between the coating material 12 and the workpiece substrate. The diffusion bond does
7 not have the interface boundary which is usually the site of failure.

8

9 The diffusion bond is created by subjecting the coated workpiece substrate to a hot
10 isostatic pressing (HIP) treatment. The appropriate hot isostatic pressing treatment
11 parameters are selected depending on the coating, the workpiece substrate and the final
12 attributes that are desired (Step Seven). The hot isostatic pressing treatment is performed
13 on the coated workpiece substrate to obtain a metal product having the desired finished
14 dimensions and diffusion bonding between the coating material 12 and the workpiece
15 substrate (Step Eight).

16

17 By proper formation of the workpiece substrate, the final dimensions of the finished
18 workpiece product can be accurately achieved through the precise control of the build up
19 of coating material 12 when the HVOF plasma spray process is performed.

1 Alternatively, the HIP treated and HVOF coated workpiece substrate may be machined to
2 final dimensions as necessary (Step Nine).

3

4 HIP treatment is conventionally used in the densification of cast metal components and as
5 a diffusion bonding technique for consolidating powder metals. In the HIP treatment
6 process, a part to be treated is raised to a high temperature and isostatic pressure.

7 Typically, the part is heated to 0.6 - 0.8 times the melting point of the material
8 comprising the part, and subjected to pressures on the order of 0.2 to 0.5 times the yield
9 strength of the material. Pressurization is achieved by pumping an inert gas, such as
10 Argon, into a pressure vessel 14. Within the pressure vessel 14 is a high temperature
11 furnace, which heats the gas to the desired temperature. The temperature and pressure is
12 held for a set length of time, and then the gas is cooled and vented.

13

14 The HIP treatment process is used to produce near-net shaped components, reducing or
15 eliminating the need for subsequent machining operations. Further, by precise control of
16 the temperature, pressure and time of a HIP treatment schedule a particular
17 microstructure for the treated part can be obtained.

18

1 In accordance with the present invention, the HIP treatment process is performed on a
2 HVOF coated substrate to convert the adhesion bond, which is merely a relatively weaker
3 mechanical bond, to a diffusion bond, which is a relatively stronger metallurgical bond.

4 In accordance with the present invention, an HVOF coating process is used to apply the
5 coating material 12 having sufficient density to effectively undergo the densification
6 changes that occur during the HIP process. A sintering heat treatment step may be
7 performed improve the density of the coating material and prevent gas entrapment during
8 the hot isostatic pressing treatment. If the coating material 12 and the workpiece
9 substrate are comprised of the same metal composition, then the diffusion bonding results
10 in a particularly seamless transition between the substrate and the coating.

11
12 As shown in Figures 2(a) through 2(d), the inventive method can be used for forming a
13 metal product having a wear resistant surface. Figure 2(a) is a schematic view showing a
14 tool substrate 10 provided in accordance with the inventive method of forming metal
15 components having a wear resistant coating. The inventive method can be employed to
16 produce, for example, a long lasting cutting tool from a relatively inexpensive cutting
17 tool substrate 10.

18

1 In accordance with this aspect of the invention, a workpiece substrate is formed to near-
2 finished dimensions. The tool substrate 10 may be a drill bit, end mill, lathe tool bit, saw
3 blade, planer knives, cutting tool inserts, or other cutting tool part. The substrate may,
4 alternatively, be something other than a tool. For example, ice skate blades and snow ski
5 edges may be treated in accordance with the present invention to obtain a long wearing
6 edge. Kitchen knives may be treated in accordance with the present invention to reduce
7 or even eliminate the need for constant sharpening. Further, products such as pen tips
8 and fishing hooks may be treated in accordance with the present invention so as to benefit
9 from long lasting durability. Nearly any metal component that could benefit from a
10 longer wearing, dense surface structure might be a candidate from the present invention.
11 For example, steam turbine erosion shields, fly ash fan blades, power plant conveyors,
12 are all subjected to wear and/or surface erosion forces. The present invention can be used
13 to provide the protective surface characteristics, as described herein, that enhance the
14 effectiveness of products such as these.

15

16 Figure 2(b) is a schematic view of the tool substrate 10 having a wear resistant coating
17 applied using an HVOF thermal spray process in accordance with the inventive method.
18 A high-density coating process, such as a hyper velocity oxy-fuel thermal spray process,
19 is performed to coat the workpiece substrate 10 with a wear resistant coating material 12

1 using, for example, an HVOF nozzle. The coating material 12 is built-up to a thickness
2 that is effective to obtain desired finished dimensions after performing a hot isostatic
3 pressing treatment.

4

5 Figure 2(c) is a schematic view of the HVOF spray coated tool substrate 10 undergoing a
6 HIP treatment process in a HIP vessel 14. The hot isostatic pressing treatment is
7 performed on the coated workpiece substrate to obtain a metal product having the desired
8 finished dimensions and diffusion bonding between the coating material 12 and the
9 workpiece substrate.

10

11 Figure 2(d) is a schematic view of the final HVOF spray coated and HIP treated tool
12 having a wear resistant coating layer diffusion bonded to the tool substrate 10. In
13 accordance with the present invention the mechanical bond formed between the parent
14 substrate and the applied coating is converted to a metallurgical bond by creating a
15 diffusion bond between the coating material 12 and the parent substrate. The diffusion
16 bond does not have the interface boundary which is usually the site of failure, thus a
17 superior product is obtained that has desired surface properties, such as wear resistance,
18 color, smoothness, texture, etc. These surface properties do not end abruptly at a bonding
19 interface (as is the case of conventional coated or brazed products), but rather remain

present to a continuously varying degree from the product surface to the parent metal. A cutting edge can be put on the tool surface by conventional sharpening techniques taking care not to remove more of the diffusion bonded coating than is necessary.

4

Figures 3(a) through 3(e) illustrate the present inventive method employed for forming a cast metal product having predetermined dimensions and surface characteristics. Figure 3(a) is a schematic perspective view of a cast metal workpiece substrate undergoing a machining operation. As shown in Figure 3(a), the cast metal workpiece is machined, if necessary, to near-finished dimensions. Figure 3(b) is a schematic perspective view of the machined cast metal component.

11

A high-density coating process, such as a hyper velocity oxy-fuel thermal spray process, is performed to coat the workpiece substrate with a coating material 12. Figure 3(c) is a schematic perspective view of the machined cast metal component having a coating applied using an HVOF thermal spray process. The coating material 12 is built-up to a thickness effective to obtain desired finished dimensions after performing a hot isostatic pressing treatment. Figure 3(d) is a schematic perspective view of the HVOF spray coated machined cast metal component undergoing a HIP treatment process in a HIP vessel 14. The hot isostatic pressing treatment is performed on the coated workpiece

1 substrate to obtain a metal product having the desired finished dimensions and diffusion
2 bonding between the coating material 12 and the workpiece substrate. Figure 3(e) is a
3 schematic perspective view of the final HVOF spray coated and HIP treated machined
4 cast metal product having a coating layer diffusion bonded to the machined cast metal
5 component.

6

7 Figure 4 is a flow chart showing the steps of the inventive method of repairing a turbine
8 engine part. The present inventive method can be used for repairing a turbine engine part
9 18, such as a blade or vane. In accordance with this aspect of the invention a turbine
10 engine part 18, which is comprised of a metal or metal alloy, is first cleaned (Step One).
11 If necessary, eroded portions of the turbine engine part 18 are welded using a weld
12 material comprised of the same metal or metal alloy as the parent or original metal engine
13 part (Step Two). The welding operation is performed to build up heavily damaged or
14 eroded portions of the turbine engine part 18. If the part is not heavily damaged, the
15 welding operation may be obviated.

16

17 The welding operation will typically produce weld witness lines. The weld witness lines
18 are ground flush to prevent blast material from becoming entrapped in the weld witness
19 lines (Step Three). Portions of the engine part that are not to be HVOF sprayed are

1 masked (Step Four), and the engine part is again cleaned in preparation for HVOF
 2 spraying (Step Five). HVOF plasma spraying of the unmasked portions of the engine
 3 part is performed (Step Six). The HVOF plasma spray material (coating material 12) is
 4 comprised of the same metal alloy as the parent or original metal engine part. The HVOF
 5 plasma spray material is applied so as to build up a cordal dimension of the engine part to
 6 a thickness greater than the thickness of an original cordal dimension of the engine part.
 7 A sintering heat treatment process may be performed to further densify the coating
 8 material. A hot isostatic pressing (HIP) treatment if performed on the coated engine part
 9 to densify the coating material 12, to create a diffusion bond between the coating material
 10 12 and the parent and weld material, and to eliminate voids between the turbine engine
 11 part 18, the weld material and the coated material (Step Seven). Finally, the engine part
 12 is machined, ground and/or polished to the original cordal dimension (Step Eight).
 13
 14 Figure 5(a) is a schematic side view and Figure 5(b) is a schematic cross-sectional view
 15 of a worn turbine engine part 18 before undergoing the inventive method of repairing a
 16 turbine engine part 18. Metal alloy components, such as gas turbine parts such as blades
 17 and vanes, are often damaged during use. During operation, gas turbine parts are
 18 subjected to considerable degradation from high pressure and, in the case of rotating
 19 components such as blades, centrifugal force in a hot corrosive atmosphere. The gas

1 Figure 6(a) is a schematic side view and Figure 6(b) is a schematic cross-sectional view
2 of the worn turbine engine part 18 showing the worn areas 20 to be repaired using the
3 inventive method of repairing a turbine engine part 18. The area enclosed by the dashed
4 lines represent the material that has been erode or otherwise lost from the original turbine
5 engine part 18. In accordance with the present invention, this area is reconstituted using
6 the same material as the original blade and using the inventive metal treatment process.
7 The worn turbine engine part 18 (in this case, a turbine blade) is first cleaned to prepare
8 the worn surfaces for welding (see Step One, Figure 4).

9
10 Figure 7(a) is a schematic side view and Figure 7(b) is a schematic cross-sectional view
11 of the worn turbine engine part 18 showing the worn areas filled in with similar weld
12 material 22 in accordance with the inventive method of repairing a turbine engine part 18
13 (see Step Two, Figure 4). In accordance with the present invention, the weld material is
14 the same as the original blade material making the bond between the weld and the
15 substrate exceptionally strong.

16
17 Figure 8(a) is a schematic side view and Figure 8(b) is a schematic cross-sectional view
18 of the welded turbine engine part 25 showing areas 24 to be built up with similar coating
19 material 12 using an HVOF spray coating process in accordance with the inventive

1 method of repairing a turbine engine part. In accordance with the present invention, the
2 coating material 12 is the same as the original blade material, again making the bond
3 between the weld and the substrate exceptionally strong.

4

5 Figure 9(a) is a schematic side view and Figure 9(b) is a schematic cross-sectional view
6 of the HVOF built up, welded turbine engine part 27 showing an area, such as the vane or
7 blade root, masked 26 before performing the HVOF spray coating process in accordance
8 with the inventive method of repairing a turbine engine part. The coating material 12 is
9 built-up to a thickness that is effective to obtain desired finished dimensions after
10 performing a hot isostatic pressing treatment (described below).

11

12 The high-density coating process may comprise performing a hyper velocity oxy-fuel
13 thermal spray process. In the case of HVOF, a fuel gas and oxygen are used to create a
14 combustion flame at 2500 to 3100°C. The combustion takes place at a very high chamber
15 pressure and a supersonic gas stream forces the coating material 12 through a small-
16 diameter barrel at very high particle velocities. The HVOF process results in extremely
17 dense, well-bonded coatings. Typically, HVOF coatings can be formed nearly 100%
18 dense, with at a porosity of about 0.5%. The high particle velocities obtained using the
19 HVOF process results in relatively better bonding between the coating material 12 and

1 the substrate, as compared with other coating methods such as the conventional plasma
2 spray method or the chemical vapor deposition method. However, the HVOF process
3 forms the bond between the coating material 12 and the substrate that occurs primarily
4 through mechanical adhesion at a bonding interface. As will be described below, in
5 accordance with the present invention this mechanical bond is converted to a
6 metallurgical bond by creating a diffusion bond between the coating material 12 and the
7 workpiece substrate. The diffusion bond does not have the interface boundary which is
8 usually the site of failure.

9

10 The diffusion bond is created by subjecting the coated workpiece substrate to a hot
11 isostatic pressing (HIP) treatment. The appropriate hot isostatic pressing treatment
12 parameters are selected depending on the coating, the workpiece substrate and the final
13 attributes that are desired. The hot isostatic pressing treatment is performed on the coated
14 workpiece substrate to obtain a metal product having the desired finished dimensions and
15 diffusion bonding between the coating material 12 and the workpiece substrate.

16

17 Figure 10 is a schematic view of the HVOF built up, welded turbine engine part 27
18 undergoing a HIP treatment process in a HIP vessel 14 in accordance with the inventive
19 method of repairing a turbine engine part.

1

2 HIP treatment is conventionally used in the densification of cast metal components and as
3 a diffusion bonding technique for consolidating powder metals. In the HIP treatment
4 process, a part to be treated is raised to a high temperature and isostatic pressure.

5 Typically, the part is heated to 0.6 - 0.8 times the melting point of the material
6 comprising the part, and subjected to pressures on the order of 0.2 to 0.5 times the yield
7 strength of the material. Pressurization is achieved by pumping an inert gas, such as
8 Argon, into a pressure vessel 14. Within the pressure vessel 14 is a high temperature
9 furnace, which heats the gas to the desired temperature. The temperature and pressure is
10 held for a set length of time, and then the gas is cooled and vented.

11

12 The HIP treatment process is used to produce near-net shaped components, reducing or
13 eliminating the need for subsequent machining operations. Further, by precise control of
14 the temperature, pressure and time of a HIP treatment schedule a particular
15 microstructure for the treated part can be obtained.

16

17 Figure 11(a) is a schematic side view and Figure 11(b) is a schematic cross-sectional
18 view of the final HVOF spray coated and HIP repaired turbine engine part 28 having a
19 similar metal coating layer diffusion bonded to the original parent substrate and welded

1 portions in accordance with the inventive method of repairing a turbine engine part. By
2 proper formation of the workpiece substrate, the final dimensions of the finished
3 workpiece produce can be accurately achieved through the precise control of the build up
4 of coating material 12 when the HVOF plasma spray process is performed.

5 Alternatively, the HIP treated and HVOF coated workpiece substrate may be machined
6 to final dimensions as necessary (Step Eight).

7

8 An experimental test piece was prepared in accordance with the inventive method of
9 treating metal components. Photomicrographs of the test piece showed the grain
10 structure and diffusion bonding of the coating material 12 and the substrate after the
11 inventive method has been performed. The HIP treatment process was performed on an
12 HVOF coated test substrate to convert the adhesion bond between the coating and the
13 substrate, which is merely a mechanical bond, to a diffusion bond, which is a
14 metallurgical bond. In accordance with the present invention, an HVOF coating process
15 is used to apply the coating material 12 having sufficient density to effectively undergo
16 the densification changes that occur during the HIP process. In the case of the test piece
17 example, the coating material 12 and the workpiece substrate are comprised of the same
18 metal composition. The diffusion bonding results in a transition between the substrate

1 and the coating that has a much stronger structural integrity and wear characteristics as
 2 compared with the conventional art.
 3
 4 The test piece was prepared by building up coating material 12 to a thickness of
 5 approximately 0.02 inches, and the composition of the test pieces was determined at
 6 seven locations (A-G) across a cross section of the piece. The composition was found to
 7 be substantially uniform across the cross-section of the test piece, as shown in the
 8 following table.

9 Table I

10 Elemental Composition

11 (Weight %)

12 <u>Element</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>
13 Aluminum	5.4	5.2	5.5	6.2	6.3	6.4	6.5
14 Titanium	0.6	0.6	1.0	0.6	1.0	0.6	0.9
15 Chromium	12.9	13.2	14.5	12.7	11.5	13.7	14.1
16 Nickel	REM	REM	REM	REM	REM	REM	REM
17 Niobium	1.4	1.5	1.8	2.1	1.7	2.3	2.6
18 Molybdenum	3.7	4.1	3.6	3.3	3.4	3.9	3.0

19

1 properties that allow the part to be safely returned to service. The inventive method of
2 repairing a turbine engine airfoil part offers substantial savings because it provides for the
3 efficient and effective repairing of expensive engine parts which otherwise might have
4 been discarded.

5

6 As shown in Figure 13 in accordance with another aspect of the present invention, the
7 reclassification of a gas turbine engine airfoil part is obtained. The dimensional
8 differences between pre-reclassified dimensions of the buttresses of a turbine engine
9 airfoil part and desired post-reclassified dimensions of the buttresses are determined
10 (Step One). That is, the change in shape of the inner buttress and outer buttress necessary
11 to obtained a desired angular relationship between the airfoil section and the buttresses is
12 determined. Build-up thickness of coating material required to obtain the desired post-
13 reclassified dimensions of the buttresses is determined (Step Two). A high-density
14 coating process, such as HVOF, is used to coat the buttresses of the turbine engine airfoil
15 part with a coating material (Step Three). The portions of the part that are not to be built
16 up, such as the airfoil section and parts of the buttresses, may be masked before applying
17 the high-density coating. Also, some of the coated surfaces of the part may need to be
18 built up more than others. The coating material is applied at least to the determined
19 build-up thickness of coating material effective to obtain the desired post-reclassification

1 dimensions after performing a hot isostatic pressing treatment, and after the selective
2 removal of some of the original buttress material and some of the built up coating
3 material.

4

5 As discussed herein, the coating material comprises a metal alloy capable of forming a
6 diffusion bond with the substrate of the turbine engine airfoil part. After the coating
7 material is applied, the sintering heat treatment process may be performed (Step Four) to
8 prevent gas entrapment of the coating material and/or the diffusion bonding area during
9 the hot isostatic pressing process. Then, the hot isostatic pressing process is performed so
10 that the buttresses of the turbine engine airfoil part have a robust diffusion bonding
11 between the coating material and the original material of the buttresses (Step Five).

12 Having built up the appropriate dimensions of the inner buttress and outer buttress, the
13 reclassification of the part is obtained by selectively removing the original buttress
14 material and, if necessary, some of the built up material until the angular relationship
15 between the airfoil section and the inner and outer buttresses is obtained (Step Six). The
16 material can be removed through milling, grinding, or other suitable and well known
17 machining operations. Further, to facilitate obtaining the correct dimensions the
18 centerline position of the airfoil part can be located and held by mounting the part in a
19 suitable holding fixture when machining the buttresses.

1

2 The fixture may be so constructed so that a vane that has at least a minimum amount of
3 material built up on its buttresses can be machined and reclassified. In this case, it may
4 not be necessary to determine the dimensional differences or the required build-up
5 thickness. Rather, the inventive high density coating and HIPing process (and, if needed
6 sintering) can be performed to build up at least the minimum amount of material
7 diffusion bonded to the buttresses. Then, the vane is placed in the fixture and the excess
8 material (both original buttress material and the built-up material) is machined until the
9 buttresses have been reshaped and the vane reclassified as intended or restored to
10 original.

11

12 The class of a turbine engine vane is defined by the angular relationship between the
13 airfoil section and the inner and outer buttresses. The inventive recast process is utilized
14 to change or restore the original class of a turbine engine airfoil part by building up
15 sufficient material on the inner buttress and the outer buttress so that the buttresses can
16 then be machined to create the desired angles α and α' (shown in Figures 14(b) and
17 14(c)) and reclassify the vane.

18

1 All buttresses are dimensionally the same and all airfoils are dimensionally the same for
2 all classes of vanes. In accordance with the present invention, the airfoil centerline
3 position is held by mounting the vane in a fixture, and the buttresses are machined to
4 obtained to desired reclassification parameters.

5

6 The class of a turbine engine vane 20 is defined by the angular relationship between the
7 airfoil section 22 and the inner buttress 24 and outer buttress 26. The inventive recast
8 process is utilized to change or restore the original class of a turbine engine airfoil part by
9 building up sufficient material on the inner buttress 24 and the outer buttress 26 so that
10 the buttresses 24, 26 can then be machined to create the desired angles α and α' (shown
11 in Figures 14(b) and 14(c)) and reclassify the vane 20.

12

13 All buttresses 24, 26 are dimensionally the same and all airfoils are dimensionally the
14 same for all classes of vanes. In accordance with the present invention, the airfoil
15 centerline position is held by mounting the vane 20 in a fixture, and the buttresses 24, 26
16 are machined to obtained to desired reclassification parameters.

17

18 Figure 14(a) is a front view of a vane 20 from a gas turbine engine showing the airfoil
19 section 22, the outer buttress 26 and the inner buttress 24. In accordance with this aspect

1 of the invention, it is first determined what dimensions of the inner buttress 24 and outer
2 buttress 26 need to be adjusted in order to obtain the desired reclassification of the vane
3 20. Having determined the dimensional differences between the pre-reclassified
4 buttresses 24, 26 and the post-reclassified buttresses 24, 26, it is next determine how
5 much material must be added, and where the material must be added so that the buttresses
6 24, 26 can be reshaped.

7
8 Figure 14(b) is a partial top view showing the outer buttress 26 and angle α indicating the
9 angular relationship between the airfoil section 22 and the outer buttress 26 and Figure
10 14(c) is a partial bottom view showing the inner buttress 24 and angle α' indicating the
11 angular relationship between the airfoil section 22 and the inner buttress 24. In
12 accordance with the present invention, the vane 20 is reclassified by changing the shape
13 of the buttresses 24, 26 so that the angles α and α' are changed resulting in a changed
14 angle of attack of the airfoil section 22, and thus reclassification of the vane 20.

15
16 Figure 14(d) is a partial left-side view showing the leading edge foot 28 of the inner
17 buttress 24 and the outer foot front face 30 of a buttress rail 32 of the outer buttress 26
18 and Figure 14(e) is a partial right-side view showing the trailing edge foot 34 of the inner
19 buttress 24 and the other buttress rail 32 of the outer buttress 26. In accordance with the



1 present invention, the surfaces of the buttresses 24, 26, such as the leading edge foot 28,
2 center log 36, trailing edge foot 34 (inner buttress 24), and the outer foot front face 30
3 and buttress rails 32 (outer buttress 26) are selectively built up and machined so that the
4 angle of attack of the airfoil section 22 is adjusted. The build up of material on the
5 buttresses 24, 26 may be uniform, and then the buttresses 24, 26 machined to selectively
6 remove portions of the original substrate and portions of the build up material. To reduce
7 machine costs, the surfaces of the original buttresses 24, 26 that are going to be machined
8 may be masked before the buildup material is applied. In this case, the buildup material
9 will not have to be later machined along with the original substrate to reshape the
10 buttresses 24, 26 24, 26.

11
12 A fixture for holding the vane 20 during the machining operation(s) may be so
13 constructed so that the vane 20 having at least a minimum amount of material built up on
14 its buttresses 24, 26 can be machined and reclassified. In this case, it may not be
15 necessary to determine the dimensional differences or the required build-up thickness.
16 Rather, the inventive high density coating and HIPing process (and, if needed sintering
17 and other processes described herein) can be performed to build up at least the minimum
18 amount of material diffusion bonded to the buttresses 24, 26 24, 26. Then, the vane 20 is
19 placed in the fixture and the excess material (both original buttress material and the built-

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1 up material) is machined until the buttresses 24, 26 have been reshaped and the vane
2 reclassified as intended.

3

4 The resulting reclassified vane has inner and outer buttresses with the mechanical
5 properties required for safe return to active service in an operating gas turbine engine.

6 The diffusion bonding between the applied coating material built up on the buttresses and
7 the original buttress substrate ensures, as substantiated by the test results discussed
8 herein, that the reclassified vane can be safely returned to active service.

9

10 With respect to the above description, it is realized that the optimum dimensional
11 relationships for parts of the invention, including variations in size, materials, shape,
12 form, function, and manner of operation, assembly and use, are deemed readily apparent
13 and obvious to one skilled in the art. All equivalent relationships to those illustrated in
14 the drawings and described in the specification are intended to be encompassed by the
15 present invention.

16

17 Therefore, the foregoing is considered as illustrative only of the principles of the
18 invention. Further, since numerous modifications and changes will readily occur to those
19 skilled in the art, it is not desired to limit the invention to the exact construction and

